

University of Wollongong

Research Online

Faculty of Engineering - Papers (Archive)

Faculty of Engineering and Information
Sciences

1-1-2005

On-site nutrient removal using a 5-stage biological reactor

Mohammed J. Mowlaei

University of Wollongong

Dharmappa Hagare

University of Western Sydney, hagare_dharmappa@uow.edu.au

Muttucumaru Sivakumar

University of Wollongong, siva@uow.edu.au

Follow this and additional works at: <https://ro.uow.edu.au/engpapers>



Part of the [Engineering Commons](#)

<https://ro.uow.edu.au/engpapers/1660>

Recommended Citation

Mowlaei, Mohammed J.; Hagare, Dharmappa; and Sivakumar, Muttucumaru: On-site nutrient removal using a 5-stage biological reactor 2005, 297-303.

<https://ro.uow.edu.au/engpapers/1660>

Research Online is the open access institutional repository for the University of Wollongong. For further information contact the UOW Library: research-pubs@uow.edu.au

ON-SITE NUTRIENT REMOVAL USING A 5- STAGE BIOLOGICAL REACTOR

Mohammad J. Mowlaei¹, Dharmappa Hagare^{1A} & Muttucumaru Sivakumar¹

¹Sustainable Earth Research Centre, School of Civil, Mining & Environmental Engineering, University of Wollongong, NSW, Australia, ^{1A}Currently Principal, Sterling College, Sydney

Abstract

Attempts to remove nutrients from municipal wastewater have traditionally been undertaken through physical, chemical and biological methods. However, not many efforts have been made to remove nutrients in on-site wastewater treatment systems. This paper represents the experimental results of an on-site biological nutrient removal process with the potential of wastewater reuse.

The performance of this pilot-scale on-site biological reactor was evaluated according to Biochemical oxygen demand (BOD₅) Total suspended solid (TSS), Total nitrogen (TN) and Total phosphorus (TP) removal efficiencies. The data revealed that this form of on-site wastewater treatment system is capable of removing up to 94% of BOD₅, 97% of TSS, 86% of TN and 81% of TP. During the experimental period of one year the system was quite stable, requiring the minimum amount of maintenance and relatively low operational cost compared to other aerated wastewater treatment systems (AWTS). Based on the experimental data this on-site system can easily provide high quality reusable wastewater and can be used as a new alternative technology for the promotion of water conservation strategies.

Keywords

Anaerobic, Anoxic, Aerobic, AWTS, Biomedia, Nutrient, On-site

1 Introduction

The removal of nutrients and other dissolved and particulate biodegradable constituents in wastewater can be accomplished biologically using a variety of microorganisms. In this attached growth process, the microorganisms responsible for the conversion of nutrients are attached to an inert plastic biomedia "Accupac-1200".

The biological nitrogen removal is a two-step process. In the first step- nitrification, ammonia (NH₃-N) is oxidised to nitrite (NO₂-N) and subsequently to nitrate (NO₃-N) and in the second step- denitrification, nitrate (NO₃-N) is biologically reduced to nitric oxide (NO) and nitrous oxide N₂O and nitrogen gas (N₂) [2].

In the biological removal of phosphorus, the phosphorus in the influent wastewater is incorporated into cell biomass, which subsequently is removed from the process as a result of sludge wasting. The reactor configuration utilised for phosphorus removal is comprised of an anaerobic zone that is placed ahead of an anoxic and an aerobic zone. Under anaerobic conditions, phosphorus-accumulating organisms (PAO) will assimilate fermentation products such as volatile fatty acids (VFAs) into storage products within the cells with the simultaneous release of phosphorus from stored polyphosphates. Subsequently under anoxic

and aerobic conditions, the energy that is produced by the oxidation of storage products will help to increase the amount of polyphosphate storage within the cells [2].

The specific objectives of this study are:

- To investigate nutrient removal from residential wastewater using on-site wastewater treatment systems.
- To evaluate the level of treatment taking place in each of the chambers, in order to determine the overall quality of the effluent.
- To determine the suitability of a 5 chamber AWTS for producing reusable wastewater.
- To identify appropriate design parameters for designing a 5 chamber AWTS system.

2 Experimental Method

The design of a 5-chamber system comprising anaerobic- anoxic- aerobic- anoxic and aerobic stages for nitrogen and phosphorus removal from residential wastewater (collected at Bellambi Wastewater Treatment Plant) was proposed in early 2003. In April 2003 a pilot scale system was set up at the Engineering Innovation and Education Centre of the University of Wollongong. This pilot scale tank was made from 6 mm thick perspex with the overall dimensions of 2000 mm length, 150 mm width and 300 mm depth. This system comprised of a nutrient removal system consisting of 5 zones, a final clarifier and a sand filter for final polishing of the effluent. A schematic of the system is shown in Figure 1.

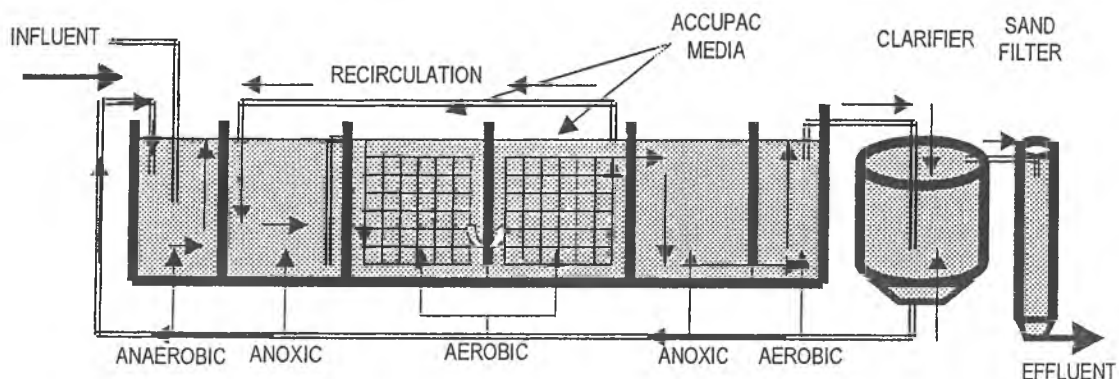


Figure 1: Schematic of the Biological Reactor with Final Clarifier and Sand Filter Polishing

This system was primarily designed to remove nitrogen by aerobic biological nitrification and subsequent denitrification in anoxic zones. The nitrified effluent from the end of the first aerobic zone was pumped back to the head of the first anoxic zone, where it was introduced into the incoming wastewater and mixed under anoxic conditions for the reduction of nitrate to nitrogen gas. The second anoxic zone was provided for additional denitrification. Biological phosphorus removal was initiated in the anaerobic zone (first chamber) and it was removed as the result of sludge wasting in the subsequent anoxic and aerobic zones (second and third chambers). The last aerobic zone re-oxygenated the process flow stream and stripped it of any remaining dissolved nitrogen gas and minimised the release of phosphorus in the final clarifier.

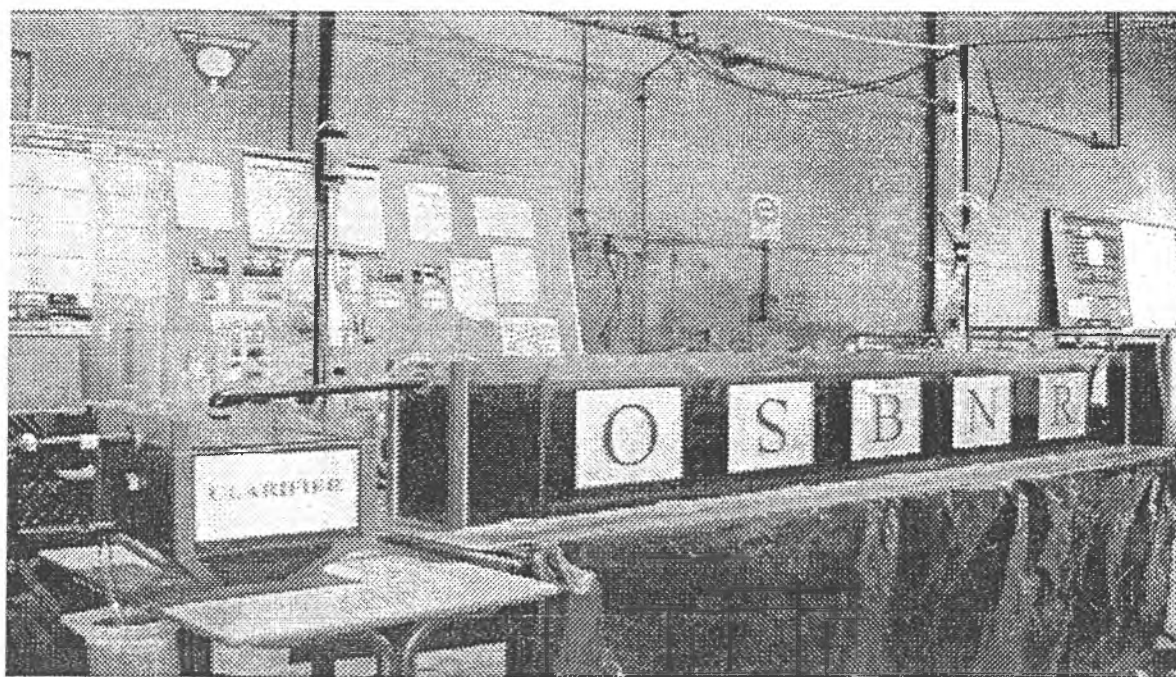


Figure 2: Pilot scale On-Site Biological Nutrient Removal (OSBNR)

3 Design parameters

The most important parameters in designing a highly efficient on-site BNR system are illustrated in the Table 1. One of the most critical design parameters is the Hydraulic Retention Time (HRT) of each chamber. Longer HRT may lead to septicity, excess nitrification or either undesirable secondary release of phosphorus while shorter HRT may not give enough time for sedimentation of suspended solids, proper denitrification and sufficient release of phosphorus in anaerobic chamber. The internal recycle ratio from the aerobic chamber to the first anoxic chamber is another important factor and must be kept to a ratio which does not cause over excess dissolved oxygen in the anoxic chambers. The specific surface area of biomedial plays an important role in organic loading rate.

4 Results and Discussion

The influent and effluent of the pilot scale AWTS were analysed for various wastewater quality parameters such as temperature, dissolved oxygen (DO), pH, turbidity, total suspended solids (TSS), biochemical oxygen demand (BOD₅), total kjeldahl nitrogen (TKN), ammonia-nitrogen (NH₃-N), organic-nitrogen (Org-N), nitrate-nitrogen (NO₃-N) and total phosphorus (TP) over twelve months period from January 2004 to December 2004. Table 2 shows the variation in influent and effluent wastewater parameters with their minimum, maximum and average values during the sampling period. The results were compared with the data obtained for conventional AWTS [3] and the primary difference was the higher removal efficiency of nitrogen and phosphorus for the present system.

4.1 Biochemical Oxygen Demand (BOD₅)

The influent BOD₅ varied between 168 mg/L and 234 mg/L, with the average concentration of 189 mg/L while the effluent BOD₅ concentration had the minimum of 3 mg/L and maximum of 16 mg/L with the average of 5 mg/L. The average effluent BOD₅ of 5 mg/L was an indication of a significant removal efficiency of this treatment system. Figure 3 illustrates

the removal efficiencies of each chamber. The first chamber and second chamber had the average removal efficiency of 5% and did not contribute to the BOD₅ removal significantly.

However, as expected the third chamber (aeration chamber) contributed towards significant BOD₅ removal with the average removal rate of 41% and the fifth chamber provided the second highest contribution towards BOD₅ removal of 31%. The fourth chamber contributed moderately with the average removal of 28% and the clarifier and sand filter had the average removal efficiencies of about 10%. The present system showed slightly lower overall BOD₅ removal of 94% compared to conventional AWTS of 95%.

Table 1: Design parameters for designing an OSBNR system

Parameters	Present study
Flow rate (mL/min)	65
Internal recycle (mL/min)	200
Specific surface area of Biomedia (m ² /m ³)	226
Total surface area (m ²)	18.3
Anaerobic Contact time (h)	2
First anoxic contact time (h)	4
First aerobic contact time (h)	10
Second anoxic contact time (h)	4
Second aerobic contact time (h)	1.5
Final Clarifier contact time (h)	5
Hydraulic retention time (h)	26.5
Hydraulic Loading Rate (Volumetric) (m ³ /m ³ .d)	0.89
Hydraulic Loading Rate (Surface) m ³ /m ² .d	5.1 x 10 ⁻³
Organic Loading Rate (Volumetric) kgBOD/m ³ .d	0.15
Organic Loading Rate (Surface) kg BOD/m ² .d	0.9 x 10 ⁻³
BOD Removal Rate (Volumetric) kgBOD/m ³ .d	0.14
BOD Removal Rate (Surface) (kg BOD/m ² .d)	0.86 x 10 ⁻³
Sand Filter Surface Loading Rate (m ³ /m ² .d)	11.8
Sand Filter Organic Loading Rate (kg BOD/m ² .d)	0.097
Sand Filter BOD Removal Rate (kg BOD/m ² .d)	0.051

Table 2: Influent and Effluent wastewater quality parameters

Parameters	Present study							Conventional AWTS
	Influent			Effluent			Removal (%)	Removal (%)
	Min	Max	Ave	Min	Max	Ave		
BOD ₅ (mg/L)	168	234	189	3	16	5.0	94	<95
TSS (mg/L)	158	368	216	2	14	3.0	97	<95
TN (mg/L)	17	54	41	3	12	5.0	86	<50
TP (mg/L)	4	15	9	1	7	2.5	81	<40

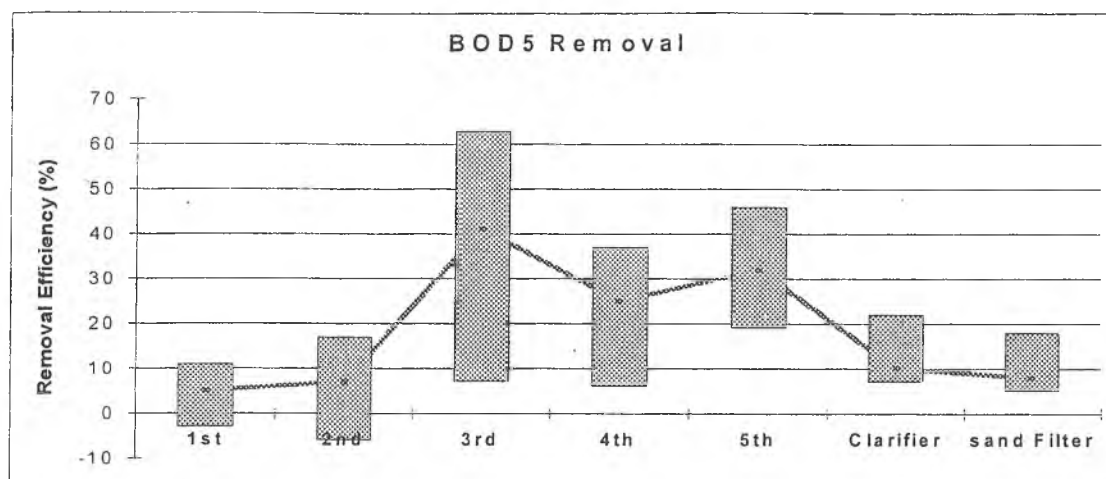


Figure 3: BOD₅ removal efficiencies in each chamber

4.2 Total Suspended Solids (TSS)

The comparison of the influent and effluent TSS values indicates the occurrence of a high TSS removal efficiency in this system. The influent TSS concentration varied between 158 mg/L to 368 mg/L and the effluent TSS concentration was ranging from 2 mg/L to 14 mg/L. This system was capable of reducing the influent average TSS concentration from 216 mg/L to 3 mg/L, well below the required limit of 10 mg/L by NSW Department of Health [1]. Figure 4 shows the average, minimum and maximum removal efficiencies in each chamber.

The first chamber (anaerobic chamber) and second chamber (anoxic chamber) had an average removal rate of about 10% and contributed to TSS removal to some extent, however the TSS concentration dropped about 20% in the third and fifth chamber due to the attached growth of biofilms over the surface of biomedica and sludge wasting. The final clarifier was also responsible for up to 20% of TSS removal. In the final polishing the sand filter had the removal efficiency of about 10%. The overall removal rate of the pilot plant of 97% was slightly higher than the conventional AWTS of 95%.

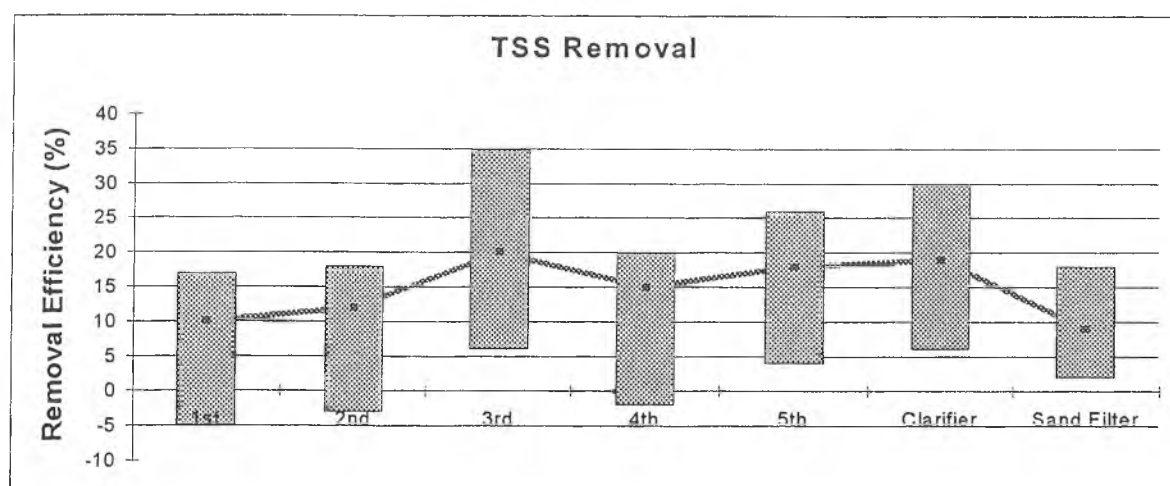


Figure 4: TSS removal efficiencies in each chamber

4.3 Total Nitrogen (TN)

In this study the influent TN ranged from 17 mg/L to 54 mg/L with an average of 41 mg/L. Metcalf and Eddy Inc. et.al (2003) indicates a range of 20 mg/L to 70 mg/L of total nitrogen for domestic wastewater and suggests that this range corresponds to medium strength wastewater.

The average effluent concentration of 5 mg/L was an indication that this treatment system provides conditions for significant nitrogen removal with the overall removal efficiency of 86% compare to conventional AWTS of about 50% nitrogen removal. Figure 5 demonstrates the removal efficiency of each chamber.

The first chamber did not contribute to TN removal significantly and the third and fifth chambers had the average TN removal efficiencies of about 8%. The highest nitrogen removal of 32% and 27% occurred in the second and fourth chambers respectively (anoxic chambers) due to the denitrification process. The clarifier had a removal efficiency of about 10% and the sand filter with removal efficiency of about 5% did not contribute to this process significantly.

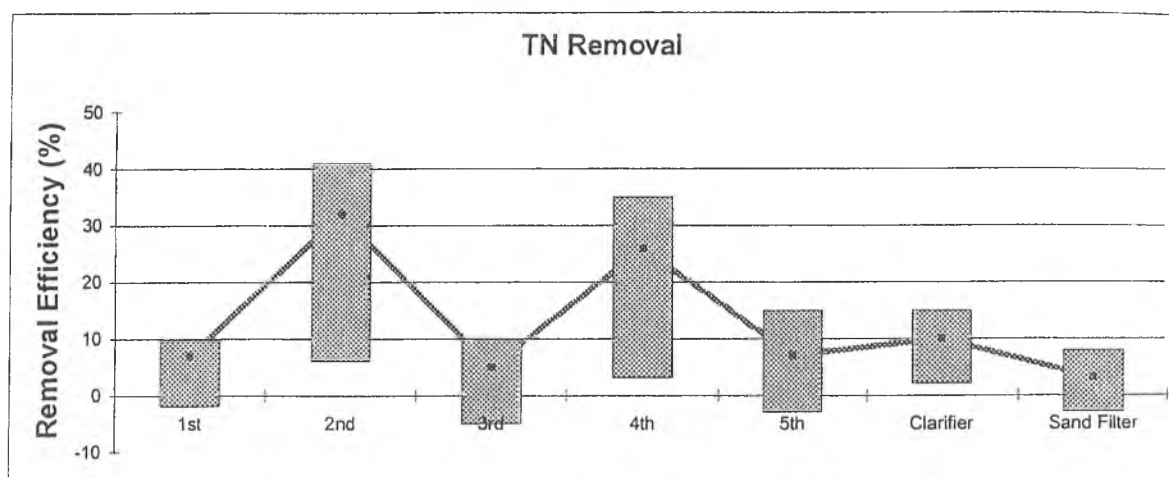


Figure 5: TN removal efficiencies in each chamber

4.4 Total Phosphorus (TP)

The average total phosphorus concentration of 9 mg/L was observed for the influent wastewater, similar to TP concentration reported for the medium strength untreated household wastewater [2]. The pilot plant produced effluent with TP concentration of 2.5 mg/L, slightly above the required limit set by NSW Department of Health [1]. Figure 6 shows the removal efficiency of each chamber.

The experimental data revealed that the release of phosphorus took place in the first chamber however the removal of phosphorus had taken place in the subsequent anoxic and aerobic chambers. The second and third chambers contributed significantly to the removal of phosphorus from influent wastewater with high removal rates of 19% and 31% respectively. The fourth chamber contributed moderately to TP removal with about 12% removal. The final clarifier and sand filter had the low removal of about 5%.

A comparison of the present design removal efficiency of 81% with conventional AWTS of 40% revealed that this system can remove a significant amount of phosphorus from the

influent, however modifications are needed to improve the removal efficiency of the pilot tank for phosphorus removal.

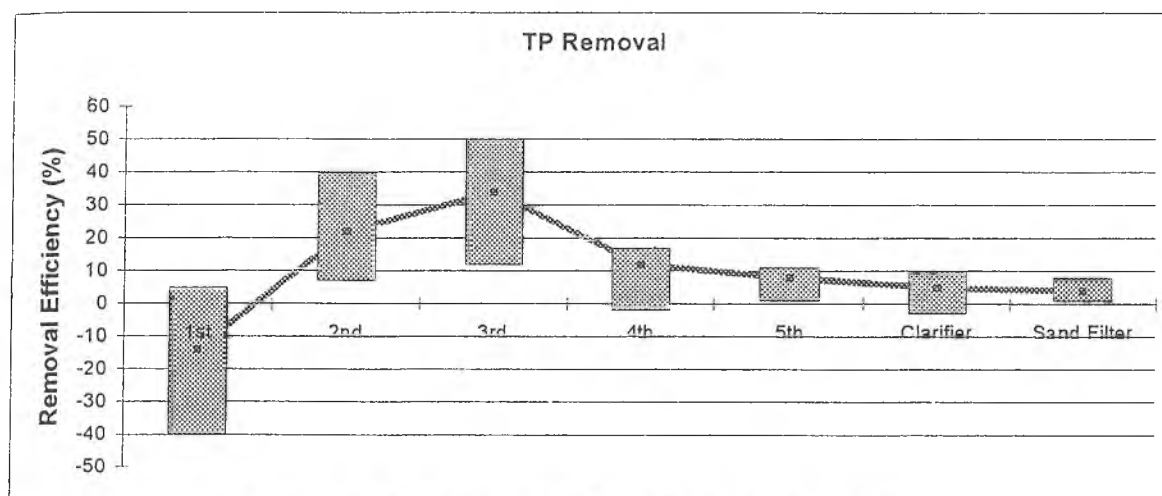


Figure 6: TP removal efficiencies in each chamber

5 Conclusion

On-site sewerage facilities have been and will remain a necessary and appropriate component of sustainable wastewater infrastructure, particularly in the rural and remote areas of Australia and around the world. The BOD₅ and TSS removal efficiencies of this innovative design were as high as 94% and 97% respectively with treated effluent average concentrations of 5 mg/L of BOD₅ and 3 mg/L of TSS.

The total nitrogen removal efficiency of 86% was also quite satisfactory and the system produced the effluent quality with total nitrogen concentration of 5 mg/L. TP load removal showed a weaker result with the removal efficiency of 81% and effluent TP concentration of 2.5 mg/L, which was slightly above the required level of less than 2 mg/L set by the NSW Department of Health and other regulatory authorities in Australia and around the world [1,2,3]. The sand filter contributed to the reduction of organic compounds significantly (removal of BOD₅ and TSS) but did not demonstrate a high potential for nitrogen and phosphorus removal. The effluent from the polishing sand filter is currently being tested to determine its microbiological quality for safe reuse without disinfection. Further studies are required to improve the removal efficiency of this on-site wastewater treatment system.

Acknowledgements

The authors wish to thank The Sustainable Earth Research Centre for supporting this project and Mr. Norm Gal and Ms Joanne Gorge and Mr Julian Fyfe, the Environmental Engineering Laboratory Technical staff for providing technical assistance to this project.

References

- NSW Department of Health (2001) *Domestic Wastewater Treatment Systems Accreditation Guidelines*. NSW Department of Health
- Metcalf & Eddy, Inc. (2003) *Wastewater Engineering, Treatment and Reuse*, 4th Edition, McGraw Hill, New York
- U.S. EPA. (2001) *On-site Wastewater Treatment and Disposal Systems. Technical Report EPA 625/1-01-102*. Washington, D.C., U.S. Environmental Protection Agency.